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Nicetto, Tommaso ; Longo, Federico

Abstract: OBJECTIVES: The purpose of this study was to report the clinical outcomes of traumatic appendicular bone injuries treated with supercutaneous plating. METHODS: We conducted a retrospective case series of medical records following fracture fixation using locking implants with a supercutaneous plating technique. Inclusion criteria comprised a complete clinical and radiographical follow-up until implant removal. Patient history and signalment as well as fracture configuration were recorded. RESULTS: Five appendicular long bone fractures (3 radii, 2 tibiae) were included in the study and they were all treated using conical coupling locking plates. The patient mean age was 2.3 years (range: 0.3-5.8 years) and the mean body weight 16.5 kg (range: 3-27 kg).One major (implant failure) and minor complications (delayed bone union and iatrogenic recurvatum deformity) were detected. The removal of the plates was quick and did not require general anaesthesia. All five fractures treated healed and patients were sound at final follow-up. Neither discomfort nor pain were noticed during the postoperative patient management. CLINICAL SIGNIFICANCE: The advantages related to the minimally invasive approach and implant removal could make the supercutaneous plating (SCP) an alternative to the traditional external skeletal fixation.Further clinical investigations are required before definitive treatment recommendations using this technique can be made. In consideration of some of the complications detected, the use of fluoroscopy is recommended to support the surgeon at the beginning of their SCP learning curve.

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Supercutaneous Plating for the Treatment of Traumatic Injuries of the Appendicular Skeleton in Dogs

Tommaso Nicetto[1,2] Federico Longo[2]

[1] Diagnostica Piccoli Animali — Clinica Veterinaria Pedrani, Vicenza, Italy
[2] Department of Animal Medicine, Production and Health, University of Veterinary Medicine, Padova, Italy

Address for correspondence Tommaso Nicetto, DVM, Diagnostica Piccoli Animali — Clinica Veterinaria Pedrani, Vicenza, Italy (e-mail: tommaso.nicetto@gmail.com).

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Abstract

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Methods We conducted a retrospective case series of medical records following fracture fixation using locking implants with a supercutaneous plating technique. Inclusion criteria comprised a complete clinical and radiographical follow-up until implant removal. Patient history and signalment as well as fracture configuration were recorded.

Results Five appendicular long bone fractures (3 radii, 2 tibiae) were included in the study and they were all treated using conical coupling locking plates. The patient mean age was 2.3 years (range: 0.3–5.8 years) and the mean body weight 16.5 kg (range: 3–27 kg). One major (implant failure) and minor complications (delayed bone union and iatrogenic recurvatum deformity) were detected. The removal of the plates was quick and did not require general anaesthesia. All five fractures treated healed and patients were sound at final follow-up. Neither discomfort nor pain were noticed during the postoperative patient management.

Clinical Significance The advantages related to the minimally invasive approach and implant removal could make the supercutaneous plating (SCP) an alternative to the traditional external skeletal fixation. Further clinical investigations are required before definitive treatment recommendations using this technique can be made. In consideration of some of the complications detected, the use of fluoroscopy is recommended to support the surgeon at the beginning of their SCP learning curve.

Keywords
- supercutaneous plating
- locking plate
- minimally invasive osteosynthesis
- appendicular fracture
- dog

Introduction

External skeletal fixation is a widely used and versatile surgical technique for the treatment of fractures in small animals.[1,2] The reported advantages of external skeletal fixation include a minimally invasive approach, the avoidance of aggressive dissection of the soft tissues and the absence of manipulation of fracture hematoma.[1–3]

Continued research in the area of minimally invasive fracture osteosynthesis led to the introduction of both subcutaneous and supercutaneous plating in human patients.[4] The use of locked implants was an imperative prerequisite for adopting this approach since they secure a firm connection between the plate and screws without requiring contiguity with bone cortices.[5]

Supercutaneous plating technique was described for the treatment of open fractures, non-unions, septic arthritis and distraction osteogenesis as well.[6–11] Inspired by this minimally invasive plating approach, Klos and colleagues[12] reported the first surgical outcomes in veterinary medicine, followed by a publication that focused on the

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supercutaneous plating for the treatment of a tibial fracture in a cat.[13]

One of the most relevant benefits that supercutaneous plating share with other minimally invasive osteosynthesis techniques is the avoidance of the exposure of the fracture gap, and therefore the minimization of the soft tissue trauma.[6–10] As a result, the extraosseous blood supply is substantially preserved, contributing to an early secondary bone healing.[14–16] Compared with other techniques such as minimally invasive plate osteosynthesis and minimally invasive nailing osteosynthesis, supercutaneous plating allows for a quick implant removal without the requirement of general anaesthesia.[6–13] Furthermore, in contrast with external skeletal fixation, the supercutaneous plate has the advantage of having a lower and flatter profile, which can be easily pre-contoured along the skin surface and does not strike the contralateral limb when applied in the medial areas.[10–13]

In light of limited literature in veterinary medicine on the application and clinical results of supercutaneous plating in small animals, we report our experience and outcomes of 5 long bone fractures in dogs treated with supercutaneous plating.

Materials and Methods

The clinical records of dogs presented in one referral surgical clinic, between May 2016 and December 2017, for traumatic bone injury were reviewed.

Inclusion Criteria

The inclusion criteria comprised fractures stabilized with locking implants using a supercutaneous plating technique, a complete clinical evaluation and radiographical follow-up (preoperative, postoperative and radiographical monitoring until the implant removal).

Patient Description

History and signalment of all the patients (age, weight and breed) were recorded as well as the site and the configuration of the fracture and its potential contamination (Gustilo-Anderson classification).

Surgical Technique

The temporary plate stabilization and its fixation were performed with a repeatable procedure, in accordance with the methodology previously described[13] and was obtained with a designated instrumentation (Fixin, Intrauma S.p.A., Rivoli, Italy).[17] Two Kirschner wires (Alcyon Italia S.p. a; Marena, Italy) and four pin stoppers were used to achieve a temporary stabilization of the fracture. Briefly, before plate positioning, a Kirschner wire (1.5 or 2.5 mm) was inserted into the bone and a pin stopper was locked to the Kirschner with a minimum distance of 10 mm from the skin. Thereafter, the plate was applied and held in place by a second locked pin stopper. The same procedure was, then, repeated with two more pin stoppers and a Kirschner wire in the opposite end of the plate. A standard application technique was then performed using appropriate drill bit, drill guide, depth gauge, screwdriver as well as locking screws.[17] The pin stoppers and Kirschner wires were lastly replaced with two locked screws after drilling the same holes.

Cephalexin (ICF Vet, I.C.F., Industria Chimica Fine S.r.l., Cremona, Italy) (25 mg/kg orally, twice a day for 15 days), tramadol chloride (Altadol; Formevet S.p.a., Milano, Italy) (2 mg/kg orally, twice a day for 3 days) and carprofen (Rimadyl; Zoetis Italia, S.r.l., Roma, Italy) (2 mg/kg orally, twice a day for 7 days) were prescribed. Enrofloxacin (Baytril; Bayer S.p.a., Milano, Italy) (7 mg/kg orally, once a day for 15 days) was, additionally, prescribed for open fractures. Discharge instructions included cage rest and short walks on a leash, three to four times per day until radiographical bone union was observed.

Implant Data

The following parameters associated with the implant were recorded: series of the plate (mini or large), implant thickness, number and diameter of the screws as well as the type of contouring of the implant, when performed.

Clinical Examination

Clinical re-examinations were performed by the same surgeon who executed the surgery and were not scheduled at predetermined intervals for each patient. Limb function was evaluated through both visual evaluation of the limb weight-bearing and execution of passive joint motion. A score of 0 to 4 was used to evaluate pre-and postoperative lameness of the surgically treated limb (0 = no lameness, 1= intermittent lameness, 2 = consistent weight-bearing lameness, 3 = intermittent non-weight bearing lameness and 4 = toe-touching lameness). Soft tissue swelling and signs of patient discomfort relative to the external implant were assessed by means of physical palpation of the limb, cleaning of the screw portals in the skin, evaluation of the distance between skin and plate and presence of skin lesions in the contralateral limb.

Radiographical Evaluation

Orthogonal radiographical studies were consistently performed before and after the surgery and scheduled with the owner throughout the follow-up to monitor the radiographical signs of bone union. For surgical purposes, we performed radiographs also of the contralateral limb. The radiographs taken after surgery were assessed using the triple A score (apposition, alignment and apparatus). Measurements were performed to assess frontal and sagittal alignment. For the radiographical follow-up of adult patients, radiographs were scheduled at 30 and 60 days after surgery, while for the skeletally immature patients the first radiographical recheck was recommended at 15 days of the follow-up. Bone union was radiographically diagnosed when cortical apposition was detected along with absence of fracture gap, sclerosis and reabsorption reaction.

The healing time was defined as the day of the implant removal and was recorded along with the limb alignment and implant loosening.

Complications

All the complications were reviewed and deemed as minor, if they either did not necessitate a surgical revision or required

Table 1 Data related to signalment, site of the fracture and technical specification for the implant used for each case

Case	Age (years)	Weight (kg)	Fracture site	Open/Closed fracture	Plate series	Plate thickness (mm)	Number of screws	Screw diameter (mm)
1	4.2	13	Radius-Ulna	Grade 1 open	Large	2	4	3.5
2	0.9	3	Radius-Ulna	C	Mini	1.2	4	2.5
3	0.3	13	Tibia	C	Large	2	6	3.5
4	0.5	12	Tibia	C	Large	2	6	3.5
5	6	26	Radius-Ulna	Grade 2 open	Large	2	6	3.5
					Large	2.5	6	3.5

only the sedation. Major complications instead required general anaesthesia and a surgical revision.[18,19]

Results

Inclusion Criteria

Five patients out of six satisfied the inclusion criteria. One case was excluded due to an incomplete radiographical follow-up. This patient was a 10-year-old dog that had a supercutaneous plate in addition to an internal osteosynthesis for the treatment of a tarsal metatarsal subluxation. The dog died, 28 days after surgery, due to a gastric dilatation volvulus syndrome.

Patient Description

The mean age of the patients was 2.4 years (0.3–6 years) and the mean body weight was 13.4 kg (3–26 kg) (►**Table 1**). The breeds were two mix-breed dogs, one toy Poodle, one Weimaraner and one Bernese mountain dog.

Overall, three distal radioulnar and two diaphyseal tibial fractures were treated with the supercutaneous plating technique.

The configuration of the radioulnar fracture was one simple transverse laterally displaced (case 1, ►**Fig. 1A**), one short oblique with longitudinal contraction of the fragments caudally displaced (case 2, ►**Fig. 1B**) and one long oblique medially displaced (case 5, ►**Fig. 1E**). The tibial fractures were both spiral with mild lateral displacement (cases 3 and 4, ►**Fig. 1C**, **1D**). Additionally, case 3 had a segmental fibular fracture (►**Fig. 1C**). Two out of five patients suffered an open fracture (case 1: grade 1; case 5: grade 2).

Surgical Technique

All patients had a preoperatively physical status classified according to the American Society of Anesthesiologists as grade 1. The dogs were anaesthetized and aseptic preparation for surgery was made. All five patients were treated with

Fig. 1 Pre- and postoperative radiographical study of five appendicular fractures (**A–E**) treated using locking plate using supercutaneous plating technique. Note in part (**B**) an initial screw placement into the radius was attempted, but it was then intraoperatively modified to enhance the spanning of the fracture gap and plate positioning as the implant was considered too close to the carpus.

Fig. 2 Postoperative images of the supercutaneous plating. Observe the contouring of the implants in three out of five cases (**A**–**E**).

conical coupling locking plates (Fixin Intrauma S.r.l., Rivoli, Italy) using a supracutaneous plating technique. Preoperative contouring of the implants was performed in three out of five surgeries (cases 1, 3 and 5). In case 1, the pre-contouring was accomplished to obtain convergence of the distal screws on the axial plane and divergence of the same on the sagittal plane (►**Figs. 2A** and **3**). The purpose was to avoid impingement with extensor tendons and meanwhile achieve the desired bone purchase. In case 3 (►**Figs. 1C**, and **2C**), the contouring was obtained via bending and twisting of the

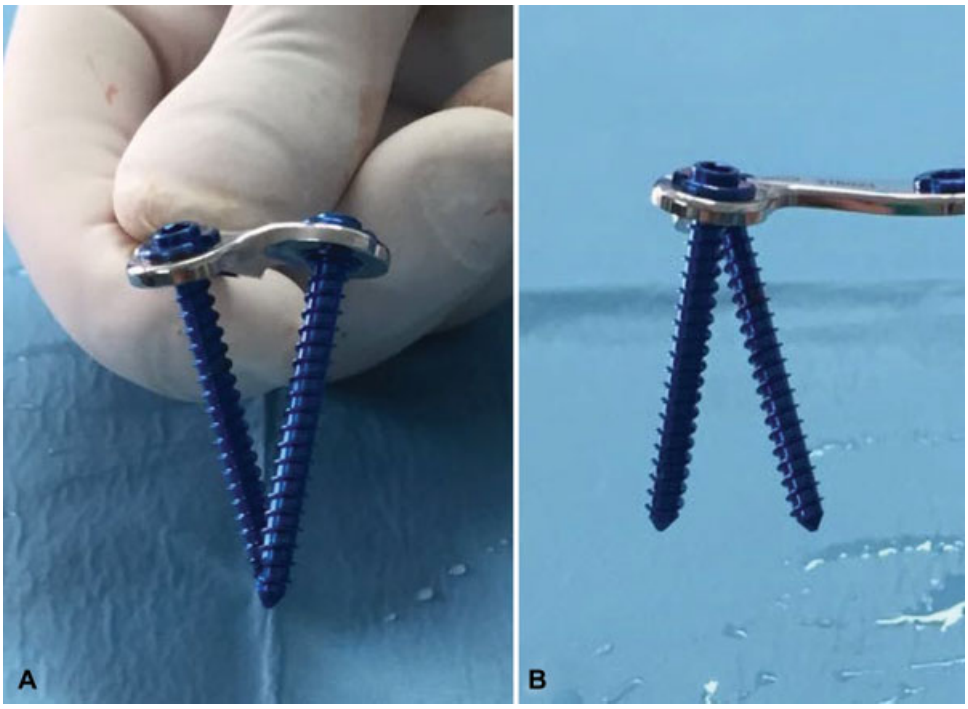

Fig. 3 Pre-contouring of a tibial plateau levelling osteotomy plate. Observe the achieved convergence of the distal screws on the axial plane (**A**) as well as the divergence of them on the sagittal plane (**B**).

implant, whereas in case 5, the two plates were bent (►**Fig. 2E**).

Traction and indirect closed reduction by means of fragments handling and bone reduction forceps were performed in all the fractures treated, without the use of fluoroscopy.

Regarding the external implant positioning, plates were applied craniomedially (►**Figs. 1A**, **1B**, **1E**, **2A**, **2B**, **2E**) for radioulnar fractures (cases 1, 2 and 5). For tibial fractures, the plates were placed onto the medial surface of the skin (►**Figs. 1C**, **1D**, **2C**, **2D**).

Temporary stabilization of the fracture allowed for checking the positioning of the plate before the insertion of the locked screws and maintaining a predetermined offset between the skin and implant.

Implant Data

The implant data are summarized in ►**Table 1**. All fractures were treated using the Fixin mini (1.9–2.5 mm) and standard series (3.0–3.5 mm). In one out of five cases, we used a T-plate for a radioulnar fracture (case 1), whereas in the other cases we applied straight plates of different length and thicknesses (cases 2–5). All cases had at least four cortices per fragment engaged.

Postoperative Clinical Examination

The details of each clinical follow-up are summarized in ►**Table 2**. Every dog was examined at least three times during the postoperative period. In cases 1, 2, 3 and 4, the clinical examinations did not reveal a lameness worse than grade 1. Whereas, in case 5, the owner requested a clinical re-examination, 5 days after the surgery, because of an acute worsening of the gait on the affected limb with a severe lameness. The clinical examination of the patient revealed a toe-touching lameness (grade 4), a valgus deformity as well as pain at palpation and mild effusion close to the radius. The patient was sedated and an orthogonal radiographical study was performed.

Postoperative Radiographical Evaluation

Radiographs obtained immediately after surgery showed acceptable to good apposition of the cortices in four of five cases[1,3–5] (►**Fig. 1**). The frontal alignment was always judged satisfactory whereas the sagittal alignment highlighted the presence of recurvatum in most of the fractures treated (cases 2-5) (►**Fig. 1**). The apparatus was radiographically considered correctly positioned in four out of five cases, whereas in one (case 5) case, the external plate was judged too short.

The radiographical follow-ups were performed between 5 days and 120 days after the surgery (►**Figs. 1**, **4** and **5**). ►**Table 2** shows that the case 4 required the shorter follow-up study (30 days) (►**Figs. 1D** and **4D**), while the case 5 required the longest postoperative radiographical study (5–120 days) (►**Fig. 5**). The radiographs performed at 5 days of the follow-up revealed failure of the implant with valgus deformity and unsatisfactory cortices apposition (►**Fig. 5A**). Post-revision radiographical re-evaluation showed a delayed bone union that healed at 120 days of the follow-up.

In all the cases, implant removal required only the sedation of the patients and was a quick and easy procedure that occurred with an average time of 61 days (►**Table 2**). Neither signs of pain nor post removal discomfort were noticed by the owner.

A modified Robert-Jones bandage was applied, in cases 2 and 4, for 10 and 7 days, respectively, after the plate removal, in attempt to prevent any further fracture of the screw holes.

Complications

This study identified minor and major complications. Minor complications included delayed bone unions (cases 1 and 5) and iatrogenic recurvatum deformities (cases 2, 3, 4 and 5) (►**Figs. 1** and **4**).

Delayed bone union in case 1 was managed removing one screw close to the fracture site at 90-day follow-up. Concerning the case 5, the same complication was managed through a controlled-staged dynamization removing the screws closest to the fracture gap at 30 days follow-up, the entire second implant at 60 days recheck and also another screw close to the fracture at 90-day follow-up. In this way, we noticed a progression of the bone healing avoiding a prospective non-union.

The implant failure represented the major complication (case 5) (►**Fig. 5**) and required a surgical revision; an additional external plate was necessary to re-establish the alignment of the radius and strengthen the initial construct. The first implant was re-bent, intra-operatively, to correct the iatrogenic valgus deformity and strengthened with the placement of a second longer straight plate (►**Fig. 5**).

Discussion

This retrospective study describes the use of supercutaneous plating for the treatment of traumatic injuries of the appendicular skeleton of dogs.

Table 2 Data related to clinical and radiographical follow-up and timing of implant removal for each patient

Case	Clinical follow-up (days)	Radiographical follow-up (days)	Implant removal (days)
1	15, 30	30, 60, 80, 90	60 (screw), 90 (plate)
2	14, 30	30, 45	30 (plate)
3	15, 30, 45	15, 30, 45	45 (plate)
4	14, 30	21, 30	21 (plate)
5	5, 14, 30, 60, 90, 120	5, 30, 60, 70, 90, 120	30 (3 screws), 80 (2nd plate), 120 (1st plate)

Fig. 4 Orthogonal radiographical study taken after the removal of the implants. Case 1 (**A**) 90 days, case 2 (**B**) 45 days, case 3 (**C**) 45 days, case 4 (**D**) 30 days and case 5 (**E**) 120 days.

Regarding the case selection and rationale for using supercutaneous plating technique, it may be argued that we could have also used traditional external skeletal fixation to treat the present fractures. Conceptually, unilateral external skeletal fixator and locking plates applied with a supercutaneous or an open reduction with internal fixation approach share some biomechanical principles, since they all work as monolateral fixators.[5,17] However, the rationale to use supercutaneous plating approach with locking implants, especially in subcutaneous bones, such as the tibia or the distal radius, is mainly related to the benefits that a closed approach provides,[15] while preserving the inherent features of stability (locked screw) and flexibility (long-spanning of the fracture) of a locking implant.[8,17]

Other similarities between supercutaneous plating and external skeletal fixation rely on the fixed distance of the offset between the bone and external implant,[8] the minimally invasive application technique and, therefore, the preservation of the blood supply to the fracture fragments.[14–16]

These features make supercutaneous plating and external skeletal fixation the preferred osteosynthesis methods for the treatment of open fractures.[1,2,20] The common principle when treating open fractures is to select a fixation method that provides sufficient fracture stability, while offering an easy access to the wounds and avoiding possible infection of the internal implants.[20]

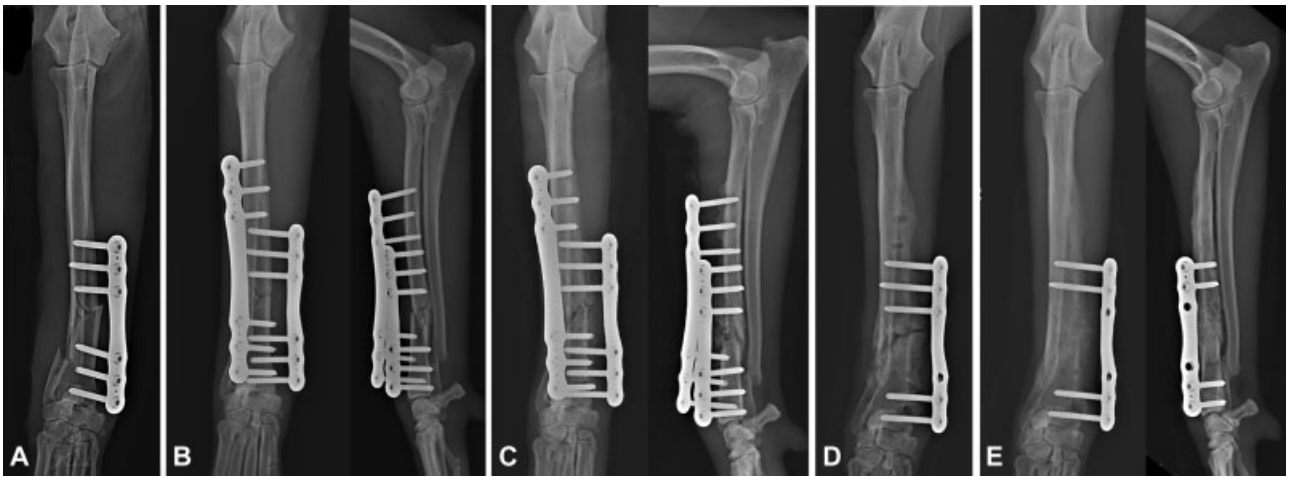

Fig. 5 Long-term radiographical follow-up of case 5. The radiographical study includes failure of the implant diagnosed at 5 days of the follow-up (**A**), the revision surgery (**B**), the orthogonal radiographs at 30 days post-revision surgery (**C**), the removal of one plate at 60 days (**D**) and preoperative radiographs at the removal of the second implant at 120 days follow-up (**E**).

In this study, we used conical coupling locking plates as external fixators to fix both the closed and open fractures, which led to a successful clinical outcome in all five patients.

Based on this limited case series, we surely cannot speculate that the treatment of the open fractures via a closed surgical procedure may have played a critical role in fracture healing. However, the closed indirect reduction and fixation minimized the iatrogenic damage to the soft tissues and periosteal vascularization and may have contributed in bone healing through the preservation of the biological environment.[15]

The advantages of using supercutaneous plating over external skeletal fixation include the lower profile of the construct, the possibility for preoperatively contouring the implant and ease of controlled-dynamization of the plate or implant removal.[8,9,13]

The frames of an external skeletal fixator could be cumbersome, heavy and often necessitate a bandaging to protect the skin of the patient from the pointed edges of the construct. Additionally, a medial external skeletal fixator could strike the contralateral limb in the swing phase while walking. On the contrary, the flat surface and the lower and less obstructive profile of an external plate decrease this tendency, so much that patients may not need any bandages. In this case series, no bandages were necessary to cover the external implant and the patients did not show any intolerance or abnormal gait due to the external implant. Furthermore, the low profile of the external plates allowed for an easy access and management of the skin wounds.

A second advantage of supercutaneous plating is the possibility of preoperatively contouring the implant to match the profiles of the skin, reducing the surgical time and bone-to-plate offset as well. The long working length of the conical coupling locked screws[17] was a concern because one potential risk to ponder is a decreased fixation stability and an augmented probability of uncoupling the head screws.[21] However, in none of the treated cases did we detect any uncoupling from the plate, even if we have remarkably increased the bone to plate distance (at least 10 mm), compared with a previous study in which this distance was 2 mm.[21] In three out of five cases, the implants were preoperatively contoured. Pre-contouring angle-stable devices, inevitably, changes the screw direction.[5,17] For this reason, the screw course and length were always checked preoperatively and intraoperatively after the pre-positioning of the implant,[13] with the aim of avoiding insufficient bone purchase and iatrogenic intra-articular screw placement.

Thirdly external osteosynthesis is, often, attractive for the treatment of long-bone fractures in skeletally immature patients. Due to the young age, potential bone growth and life expectation, the general tendency is to remove the implant as long as the bone healing is restored.[22] Sometimes it could be difficult to convince the owner to have a second surgical procedure performed when the patient has made a complete recovery. However, with external osteosynthesis, it is easier as it does not necessitate any skin incisions portals or require general anesthesia.[9,10,13] In the present case series, either the removal of some screws or the entire implant was never time consuming, required only sedation of the patients and did not cause any patient discomfort after the discharge.

Finally, we detected no screw site effusion in the cases presented, whereas superficial pin tract infection is one of the most frequently reported complications of external skeletal fixation.[23] Plausible explanations may rely on the site of implant application, that were poorly covered by soft tissues, as well on the use of self-threaded titanium screws.[5]

Potential drawbacks of supercutaneous plating over external skeletal fixation are related to the inability to angle the locked screws compared with pins, the limited availability in screw length and diameter as well as the difficulty in strengthening the initial construct.[8,13]

The monoaxial nature of locked screws implies that both the reduction of the fracture and the contouring of the implant are critical phases. We found that the application technique reported in the literature[13] ensures a predetermined plate-to-skin distance and temporary fracture fixation in which the surgeon can check the screw direction. However, sub-optimal

reductions may still occur (►**Figs. 1** and **4**). A fracture treatment via a closed approach can be challenging and cause some difficulties in achieving an accurate intraoperatively alignment. Specifically, in the present study, we reported iatrogenic recurvatum deformities as minor complications. We ascribe this complication to an initial learning curve. Fluoroscopic-guided reduction and alignment of the fracture could have probably avoided the iatrogenic sagittal malalignment in some of the cases presented.

Due to commercial restrictions in terms of screw selection, we sometimes had to opt for larger screws, to obtain the length planned on the preoperative radiographs.

Concerning the plate choice, we oversized the implants, to contrast the plausible loss of rigidity of the external plate, caused by the increase in the bone-to-plate offset.[24] As such, we used rigid constructs that may have caused delayed bone unions, which occurred in some of the cases presented.[1,5,19] We managed this minor complication through a controlled-staged dynamization, which allowed for controlling the implant flexibility. Specifically, we removed the screws closest to the fracture gap (cases 1 and 5) and also an entire second implant (case 5) to gradually reduce the stiffness of the external construct and avoid bone stress protection as well.[25]

Regarding the stability of supercutaneous plating, a recent study biomechanically compared the supercutaneous plating and external skeletal fixation in terms of torsional and axial stiffness.[26] Ang and colleagues concluded that the constructs had similar axial stiffness, with a significant difference in the mean torsional stiffness, providing biomechanical evidence to support the supercutaneous plating technique.[26]

We also used supercutaneous plating as secondary support to a primary fixation (case 5). The second external plate was useful for managing a major complication, compounded by the initial open fracture configuration. The fissures and the comminution present on the trans-cortex, the lack of anatomical reduction of the fracture, and the incorrect positioning and selection of the implant were all observed in the immediate postoperative study but were not corrected (►**Fig. 1E**). For the revision surgery, an internal fixation method would have been a recommended option. However, the application of an additional external plate had some advantages. First, we maintained the benefits of the minimally invasive principles during the second osteosynthesis, which was an easy and fast procedure. Furthermore, supercutaneous plating allowed us to perform a manageable controlled-staged dynamization of the implants throughout the prolonged follow-up (►**Fig. 5**), without general anaesthesia and open surgical approach.

In conclusion, based on our limited cases, we believe that supercutaneous plating could be considered in the future as an alternative to traditional external skeletal fixation for the treatment of long bones fractures in small animals.

However, the complications detected suggest that there is a steep learning curve and cases should be carefully evaluated to take advantage of this surgical technique. Treatment of juvenile fractures that may need quick and easy implant removal, open and highly comminuted fractures characterized by poor soft tissue envelope and vascularization may all represent favourable indications for considering supercutaneous plating.

Author Contribution

Both authors contributed to conception of study, study design, acquisition of data and data analysis and interpretation. They also drafted, revised and approved the submitted manuscript.

Conflict of Interest

The authors declare no conflict of interest related to this report.

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